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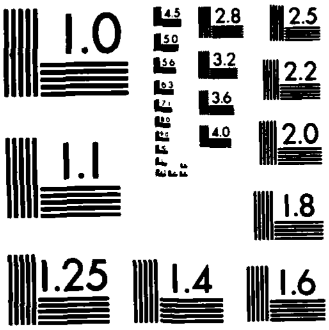

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VOLUME I

AD-A134249

INTEGRATED COMPUTER-AIDED MANUFACTURING (ICAM) ARCHITECTURE PART III

VOLUME I - ARCHITECTURE PART III ACCOMPLISHMENTS

SofTech, Inc.
460 Totten Pond Road
Waltham, MA 02154

September 1983

Final Report for September 1980 - October 1982

DTIC FILE COPY

MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

FTR110410000U
8 September 1983

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This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Richard R. Preston — 20 September 1983

RICHARD R. PRESTON, Captain, USAF — Approval Date
Project Manager
Computer Integrated Manufacturing Branch
Manufacturing Technology Division

FOR THE COMMANDER

NG Tupper — 9/23/83

NATHAN G. TUPPER — Approval Date
Chief
Computer Integrated Manufacturing Branch
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Subsystem Integration	DESIGNØ	
Technology Transfer	DESIGN1	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Integrated Computer Aided Manufacturing (ICAM) Architecture Part III was initiated to maintain and update the existing manufacturing architecture as well as develop training courses to assist in the transition of IDEF applications, concepts and procedures to other Air Force programs. This volume presents an overview of the accomplishments of Project Priority 1104, ICAM Architecture Part III.

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This report is presented in the following eight volumes:

1. Volume I - Architecture Part III Accomplishments
2. Volume II - Procedures
3. Volume III - Composite Function Model of "Design Product" (DESØ)
4. Volume IV - Composite Information Model of "Design Product" (DES1)
5. Volume V - Composite Function Model of "Manufacture Product" (MFG0)
6. Volume VI - Composite Information Model of "Manufacture Product (MFG1)
7. Volume VII - MFGØ1 Glossary
8. Volume VIII - Technology Transfer

FOREWORD

This Task IV final report covers the work performed under Air Force Contract #F33615-80-C-5109, "ICAM Architecture, Part III." This contract is sponsored by the Computer Integrated Manufacturing Branch, Manufacturing Technology Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 45433. This program is being administered under the technical direction of Capt. Richard R. Preston.

The coalition is comprised of four (4) participating companies with SofTech Corporation as the prime contractor. Ms. B.R. Davis is the SofTech Program Manager. The other participating coalition members are listed below:

D. Appleton Company	Chuck Martin
Rockwell, International	Richard Heine
Vought	Al Reingold
Downey and Small	Al Small
Grumman	Barnett Frumkin

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SECTION 1
INTRODUCTION

1.1 Project Description

The U.S. Air Force objectives are to reduce aerospace system costs by increasing productivity in aerospace manufacturing.

The ICAM Architecture has been identified as the means by which both government and industry could better understand the present manufacturing process, could represent predicted future operations, and could manage the changes which would occur in business and technology.

The first goal of the Architecture Part I Program was to record and present a common understanding of the aerospace manufacturing process by displaying its functions and their relationships. This was accomplished using the IDEFØ technique of function modeling.

The overall objective of the Architecture Part II project was to utilize and expand upon the baseline manufacturing function model developed in Part I.

The current ICAM Architecture, Part III, Project Priority 1104, was initiated to maintain and update the existing architecture, as well as to establish the transfer of technology gained from Architecture development.

The most immediate objective was to make known the architecture concepts and methods to organizations engaged in technology modernization.

In order to best meet the needs of the ICAM program, the architecture has been expanded through subsystem integration in support of the Integrated Sheet Metal Center.

The Part III (1104) Program has continued, therefore, to upgrade and expand the architecture in accordance with feedback from its users.

1.2 Scope

The effort described herein focused on composite models of the design and manufacture of aerospace products. The contract called for two types of relationship with subsystem development: the scoping of subsystems and the later integration of subsystem "AS IS" models into the relevant industry composite models. The effort was unrelated to actual subsystem development. The effort did not extend into the "TO BE" concept arena. A continuing effort to upgrade the overall models of the aerospace industry was, however, undertaken.

During the course of this contract, a concurrent project priority was examining system engineering methods. This report, therefore, deals with procedures only insofar as they were needed to meet the immediate needs of model maintenance, subsystem scoping, and model integration.

1.3 Background

The Integrated Computer Aided Manufacturing (ICAM) program has as its objective the improvement of productivity in the aerospace manufacturing sectors of American industry. It is directed toward improving productivity through the systematic application of computer technology in the design and manufacturing environment. This approach is not only ambitious but is also realistic in that it stresses the development of computer aided design and manufacturing capabilities. The integration of these computer aids into the design and manufacturing environment and among themselves will ultimately signal the success of the ICAM program.

A key to the achievement of this goal is the development of the ICAM Definition (IDEF) Methods and the ICAM composite models of design and manufacturing. The ICAM Definition Methods are a family of techniques through which analysts and laymen explore and discuss the nature of design and manufacturing systems. These techniques, developed for the ICAM program, provide a means of studying, recording, and communicating the inherent requirements and realities of the aerospace manufacturing environment. They are equally effective and valuable in many other manufacturing and non-manufacturing environments.

There are three ICAM Definition Methods: IDEFØ-Function Modeling; IDEF1-Information Modeling; and IDEF2-Dynamics Modeling. A manufacturing system is described and studied through the application of all three techniques.

The ICAM composite models of manufacturing, or architectures, records a "consensus view" of what manufacturing is and how it operates. Composite architectures are presented in two forms: the "AS IS" form-representing the way in which manufacturing is currently accomplished; and the "TO BE" form-representing the way in which manufacturing will be accomplished with computer aids in place.

Volumes III, IV, V, VI, of this report present updated IDEF1 and IDEFØ models of design and manufacturing.

These models are presented in their current state of development. It is expected that refinements will continually be made to the models as a result of their use. The vast amount of information which they contain make them impossible to comprehend by cursory examination. A tremendous effort has gone into the preparation of the models which are the end result of this project. Many stages of critique, validation, and checking have been invested to make sure that the published models are as complete, readable, consistent, and correct as possible.

As prime contractor, SofTech subcontracted the development of the integration procedure for IDEF1 to DACOM. Rockwell International and Vought Corporation participated actively in the development and testing of integration and arrow tracing procedures for IDEFØ.

Architecture Process

The necessary first step in increasing design and manufacturing productivity is to understand current design and manufacturing practice precisely and to record this understanding concisely. This development of understanding has two main phases:

- Study specific company design
- Evolve a composite understanding

Factory View

Understanding of the current manufacturing design process must be based on the detailed factual informaton which describes this process in those companies which successfully produce aerospace products. This has been called "Factory View" information. The Factory View of manufacturing and design is different for each company, for each division of each plant within a company, and even somewhat different for each organization and each individual within each plant.

Composite View

One objective of ICAM is to develop improvements in the design and manufacturing process which will be broadly applicable across the whole aerospace industry. In order to do this, it is necessary to have some understanding of "generic design and manufacturing practice." Such an understanding emphasizes the essential information, information flow, functions, and material flow necessary to all design and manufacturing processes, while deemphasizing the differences of organization and terminology among the various factory views.

The models representing this aggregate understanding are called the "Composite View" of design. The composite view models presented in this report depict design and manufacturing as they exist today in the form of functions and information models. The composite view of the existing functions and information occuring in design which has been produced in this project emphasize the technical aspects of current practice for the production of a single, new major aerospace product, such as an airplane.

Sections 3 and 5 of this volume document the procedures for creating composite views by integrating factory view models into the composite. Section 3 discusses integration of IDEFØ models. Section 5 discusses integration of IDEF1 models. Section 4 is an adjunct of Section 3 which deals in particular with improving the quality of composite IDEFØ models.

Architecture Validation

From the first week of the project, a constant process of review guides the development of the architecture. Each version of the architecture is distributed to the coalition members for comment. These versions receive a "Working" status meaning the architecture is undergoing change within the group responsible for its development. The comments cause changes ranging from complete restructuring of various levels of architecture to clarification of individual words used in detailing lower levels.

This process of revise, review, revise continues throughout the building of the model. When the coalition decides that the model, or portions of it, are ready for industry review, the status is changed to "Draft."

Every 6 months throughout the project, an Industry Review Meeting is held. The Industry Reviewers represent various manufacturing companies. They review the "Draft" version of the models to insure that they are representative of design and manufacturing as a whole. Portions of the model that receive a consensus of approval are marked "Recommended." This signifies that their content is recommended for Air Force acceptance. Portions that do not receive consensus remain at "Draft" status and receive further review and revision.

SECTION 2
EXECUTIVE SUMMARY

2.1 Participants

This program was administered under the technical direction of Captains Steven R. LeClair and Richard R. Preston.

The Coalition of participating companies was lead by SofTech, Inc. as the prime contractor. Ms. B.R. Davis was the SofTech Program Manager. Other participating coalition members were:

D. Appleton Company	Chuck Martin
Rockwell, International	Richard Heine
Vought	Al Reingold
Downey and Small Associates	Al Small
Grumman	Barnett Frumkin

2.2 Summarized Accomplishments

Architecture Part III was responsible for four (4) architecture models: an IDEFØ model and an IDEF1 model for both Design and Manufacture. The level and type of activity differed greatly among the models. The accomplishments are summarized in tabular form on the next two pages.

1104 FIRM PERIOD — RESULTS

TASK	RESULT	SIGNIFICANCE
• SCOPING	• INTEGRATED PROCESS PLANNING (5501) • INTEGRATED CENTER (6201)	• PROVIDES INDEPENDENT VIEWPOINT ON PROJECT SCOPE
• INTEGRATION	• MCDG INTEGRATION MAPPING COMPLETED	• PROVIDES VERIFICATION AND VALIDATION • EXTENDS ARCHITECTURE
• ESTABLISH DES1	• MODEL FOCUSED ON DESIGN RELEASE INFORMATION	• PROVIDES DESIGN INFORMATION NECESSARY TO SUPPORT MANUFACTURING SYSTEMS
• MFGØ GLOSSARY	• ARROW TRACE PROCEDURE DEVELOPED • MFGØ DEFINITIONS COMMENCED	• IDENTIFIES DEFICIENCIES • ENSURES CONSISTENCY • RECTIFIES OMISSIONS

Figure 2-1. 1104 Firm Period

1104 OPTION PERIOD — RESULTS

TASK	STATUS	RESULTS
• FUNCTION MODEL MAINTENANCE	• REMOVED 2-WAY ARROWS INCORPORATED CHANGES • SHORTENED INTEGRATION MAPPING PROCEDURE	• IMPROVED ARCHITECTURE FOR GLOBAL USAGE
• INFORMATION MODEL MAINTENANCE	• $IDEF_1$ INTEGRATION PROCEDURE DOCUMENTED • IPS/ICENT INTEGRATION TO MFG1 COMPLETED • INDUSTRY RECOMMENDATIONS INCORPORATED	• IMPROVED ARCHITECTURE FOR GLOBAL USAGE • WILL BETTER SUPPORT THE INTEGRATED SHEET METAL CENTER
• GLOSSARY	• MFGØ GLOSSARY FORMAT ESTABLISHED • MFGØ1 DEFINITIONS COMPLETED	• WILL SUPPORT GLOBAL USAGE • ENSURES CONSISTENCY
• TECHNOLOGY TRANSFER	• EXECUTE OVERVIEW PRESENTATION DEVELOPED • TRAIN THE PRACTITIONER COURSE DEVELOPED • TRAIN THE TRAINERS COURSE DEVELOPED	• WILL ASSIST COMMUNICATION OF USE OF IDEF APPLICATIONS CONCEPTS, AND PROCEDURES
• INTEGRATE QA/QC FCTN & INFO MODELS WITH MFGØ,1 DESØ,1		

Figure 2-2. 1104 Option Period

SECTION 3
PROJECT ACCOMPLISHMENTS

This report covers an original firm program and an option program. The firm program was carried out from 30 September 1980 through 30 June 1981. The option program was carried out from 1 July 1981 through 29 October 1982. This section surveys the accomplishments of both programs.

The structure of this section is based on the Contract Work Breakdown Structures (CWBS) of the two programs. Sections 3.1 through 3.4 cover the firm program. Sections 3.5 through 3.9 present the accomplishments of the option program.

3.1 Assume Maintenance of "AS IS" IDEFØ Models (Firm Program)

The 1104 Architecture Part III Program was primarily a maintenance effort to enhance the "AS IS" MGFØ, 1 and DESØ, 1 Models to meet the needs of its users.

The program's most immediate goal was to make known to U.S. industry the architecture, its concepts and methods to enable the successful implementation of technology modernization.

This work of refining and extending the composite architecture provides the baseline from which the "TO BE" architecture can be developed and against which the subsystems being proposed can be compared.

During the Firm Program, the coalition placed emphasis on maintaining the architecture by scoping subsystems and extending the architecture through the integration of the Manufacturing Cost/Design Guide (MCDG). In addition, a common ICAM glossary was initiated, which will aid future integration between function and information models. The glossary effort is reviewed in Section 3.3.2. Figure 3-1 summarizes the efforts and results of the firm program.

TASK	RESULT	SIGNIFICANCE
Scoping		
5501 - IPS	• Agreement Reached	• Provides Independent Agreement on Project Scope
6201 - ICENT	• General Agreement Although Clarification Requested	
3101 - CBIS	• Material Not Available Also Methodology Shortcomings	
Integration		
4503 - MCDG	• Integration Completed	• Provides Verification and Validation • Extends the Architecture

Figure 3-1

3.1.1 Scope Subsystem, 6201

Scoping of Project 6201 (ICENT) took place on January 14, 1981 in Dayton, Ohio.

The scope of Project 6201 was presented by G.E.

The Integration Team agreed with the inclusion of the nodes presented. It did, however, question the exclusion of two nodes which the Integration Team felt should be wholly or partially included within the scope of the ICENT. Other questions raised by the Integration Team dealt with interpretation of specific arrows.

3.1.2 Scope Subsystem, 5501

Scoping of Project 5501 (IPS) took place on January 14, 1981 in Dayton, Ohio. G.E.'s concept of the scope of the IPS was presented, reviewed and accepted.

3.1.3 Integrate Subsystem, MCDG

The Option III - Revised Integration Procedure (October 1980, WPAFB, Dayton, OH) was used to identify and clarify how each of the MCDGØ lowest level functions supports one or more of the DESØ functions (through Step 2 of the Integration Procedure). Because of the magnitude of effort required to perform the complete integration as delineated in the Integration Procedure, the integration of the MCDGØ subsystem into the DESØ system has been completed only through integration clarification. Specifically, the integration has not been completed at this time for the Integration Communication Analysis and the Exceptions Reporting.

The following advantages were derived from integrating the MCDGØ subsystem into the DESØ composite model:

- Integration to illustrate the MCDGØ subsystem support to the DESØ system functions,
- Documentation for use in determining how individual company operations (functions) might use the MCDGØ model to support design activities,
- Documentation for use as a training vehicle during future MCDGØ implementation and acceptance by designers,

- Documentation for determination of where further decomposition in either the MCDGØ or DESØ models might be required,

- Basis for the description of the interface of the MCDGØ subsystem and other "TO BE" subsystems,

- Integration experience for use by in-house personnel in MCDGØ implementation, other integration projects, integration, or cross-integration over other ICAM systems/ subsystems.

These results were reviewed and accepted by industry at the industry review held June 9 through 11, 1981.

3.1.4 Arrow Trace

Throughout the firm program, a careful review of the arrows in MFGØ continued. This task involved following arrows through levels of the model (via ICOM codes) and through both branching and joining of arrows. The object of this "trace" procedure was to ensure consistency and meaning of the arrow from source to target destination. This effort contributed to the glossary effort (which is discussed next) and to modification of the model at many points.

The arrow trace procedure as refined by this program is presented in full in Volume II of this report.

3.2 Establish DES1 (Firm Program)

The DESIGN1 project coalition members were the Vought Aircraft Corporation, the Grumman Aerospace Corporation, and the D. Appleton Company (DACOM). DACOM was assigned the modeler's position in the project, with Vought and Grumman providing expert source information and review commentary. The DESIGN1 project management was under the direction of the SofTech program manager for Project 1104.

After a meeting to set the Scope and Context for the development of the DES1 model, Vought and Grumman began to gather the targeted source materials. The materials were sent to DACOM which prepared the Source Material Log and the Source Data List.

It was determined the DES1 Information Model would concern itself only with the information that passed through the release function into manufacturing. All other information was considered to be outside the Scope and Context.

The modeling effort required considerable iteration. For example, as a result of one meeting the number of Entity Classes contained in the relation matrix was pared from 53 to 16. Close to one hundred Alternative Diagrams were put together and distributed for review. The collection of entity classes again grew to nearly 50. Definitions were prepared; the relation matrix was updated; and the preliminary diagrams for these 50 entity classes were put together. Function Views were built along with the Entity Class Definitions, Entity Class Diagrams, and Key Attribute Class Definitions.

The model was completed through phase 3.X; that is, the Key Attribute Classes were assigned and some Non-Key Attribute Classes were populated.

The model was reviewed at the Industry Review Meeting June 9-11, 1981. Besides the DES1 model, the effort produced proposals for making future efforts of this type more productive. These proposals are documented in Interim Technical Report, ITR110310003U, "ICAM Architecture, Part III," October, 1981 (period 01 July, 1981 - 30 September, 1981).

3.2.1 Architecture Assessment

The first coalition working meeting was held during the first week of December, 1980. The Scope and Context for DES1 were established, thus producing the effort's first kit. The meeting also established plans for initiating the collection of the required data set. It was recognized that an information model representing all aspects of design could not be developed in the time available. Therefore, the areas in which the information is transferred from Design to Manufacturing was chosen as being of primary interest. The results of this scoping were formalized in a Phase Zero Scope and Context kit.

Later, experience was to show that even greater accuracy and clarity should be sought in model scope and context definitions. It was found that many of the pieces of material that were initially collected were disposed of because they did not fall within the scope and context. Also, many of the original entity classes were eliminated because they fell outside the scope and context.

There was difficulty with the establishment of a firm scope and context because the design function can and does produce many and varied products. For example, design obviously produces detailed design drawings but also produces changes to drawings, changes in the manner of material references, changes in the details of dimensioning, changes in the application of an engineering procedure and changes in the routine for release of such drawings. Finally, it was determined that the DES1 Information Model would concern itself only with the information that passed through the release function into manufacturing.

3.2.2 Collect Data

The data required to build the DES1 model was collected initially by Vought and Grumman. The data collected was later supplemented by contributions from industry during Industry Review meetings.

3.2.3 Build Factory View

Factory views extended only through the data collection phase. The following "conventions" were employed in the conduct of the 1104-DES1 Information Modeling efforts.

- Two separate SOURCE MATERIAL LOGS were maintained. The Vought Source Material was preceded by a "VSM." The Grumman Source Material was preceded by a "GSM."

- Two Separate SOURCE DATA LISTS were maintained. In this situation the coding separated and identified source data - "VSD" and "GSD" - for Vought and Grumman respectively.

3.2.4 Builo Composite View

DES1 was developed to the point of having eighty (80) entity classes related only by specific relation classes. (There are no many-to-many relation classes). All entity class have had key classes assigned and some further populating with attribute classes has been completed. The entity classes, however, are not fully populated. This level of development is sometimes referred to as phase 3.X. That is, phase 4 of the development cycle has not been completed.

The DES1 model is presented in Volume IV of this final report.

3.3 Assume Maintenance of "AS IS" IDEF1 Models (Firm Period)

IDEF1 maintenance during the firm period included updating of MFG1, an analysis of the IDEF1 model of MCMM (MCMM1) and work on an integrated MFGØ/MFG1 Glossary.

3.3.1 Assume Maintenance of "AS IS MFG1 (Firm Program)

As a result of a review meeting held in October, 1980, the Task IV coalition had comments calling for changes to 103 entity classes of the 298 entity classes in the MGF1 model. Since a comment on any entity class could lead to a requirement to change not only the entity class itself but also all related relation classes, key classes and attribute classes, it was felt that the entire task could not be accomplished during the firm period.

A weighting procedure, therefore, was developed to select the fourteen (14) most critical entity classes with which to deal. Changes for review involving these entity classes were completed prior to the final industry review meeting.

3.3.2 MCMM1 Analysis

An analysis of an MCMM IDEF1 model was conducted to determine the feasibility of integrating that model with MFG1. The analysis established that fifteen (15) of the entity classes used in the MCMM1 model appeared to match entity classes already found in MFG1. However, it was determined that the following six (6) entity classes could not be integrated into MFG1.

- Inventory Balance (by Cell)
- Allocation (Planned distributions of specific part numbers made on specific work orders to specific sales orders)
- Operation instruction
- Part Protection Comment
- Raw Material
- Unit of Operator Assignment History.

Other criticisms of MCMM1 were also uncovered. Integration of MCMM1 with MFG1 was, therefore, deferred and completed during the option phase of the program.

3.3.3 ICAM Glossary

Although the Integrated Glossary was not initially identified as an item which would be developed during this contract, it was recognized that such a glossary would be beneficial to the program in terms of MFGØ1 and DESØ1 clarification and would also provide a mechanism to assist in relating (integrating) the architectures. Such a glossary had also been recommended by the Industry reviewers. Therefore, the coalition with Air Force concurrence, recommended working on reconciling the glossaries between MFGØ1 and DESØ1 and disseminating these results both to industry and to the subsystem contractors.

An Integrated Glossary format was proposed as the method by which the results of the coalition's glossary definition work would be presented.

Papers on 'Glossary Maintenance' and on the 'Conceptual Framework for Glossary' were written in order that the coalition's view of how the glossary relates to the broader aspects of the ICAM program would be recorded. Establishment of definitions was commenced. This effort was expanded during the option period. Results of the effort are documented in Volume VII of this report.

3.4 Firm Period Validation (Firm Program)

From the first week of the project, a constant process of review guided the development of the architecture. Each version of the architecture and procedures was distributed to the coalition members for comment. These versions received a "Working" status, meaning the architecture or procedure was undergoing change within the group responsible for its development. The comments caused changes ranging from complete restructuring of various levels of architecture to clarification of individual words used in detailing lower levels.

This process of revision and review continued throughout the building of the procedures and architectures. When the coalition decided that each model, or portions of it were ready for industry review, the status was changed to "Draft".

Every 6 months throughout the project, an Industry Review Meeting was held. The review meeting for the firm program was held June 9 thru 11, 1981 at Wright-Patterson Air Force Base, Ohio. The Industry Reviewers represented various manufacturing companies. They reviewed the "Draft" version of the models to insure that they were representative of current practice. Portions of the model that received a consensus of approval were marked "Recommended." This signified that their content was recommended for Air Force acceptance. Portions that did not receive consensus remained at "Draft" status.

Each participant also submitted a report summarizing his comments. These comments were combined with those noted during the meeting to provide a basis for the development which was to occur during the option program.

3.5 Function Model Maintenance (Option Program)

Maintenance of the function model during the option program was focused on five areas; arrow trace, two-way arrow removal, incorporation of comments from the review meeting of 9 June 1981, integration of QAØ, and documentation on MFGØ of the results of subsystem integration.

3.5.1 Arrow Trace

The arrow trace procedure begun during the firm period (see Section 3.1.5) was continued. The close examination of MFGØ required by this task produced a large body of suggested changes. These changes varied greatly and were categorized by relative significance. Although no numerical breakdown of the amount of changes in each category is available, suffice it to say that there were many more minor changes than major ones.

3.5.2 Remove Two-Way Arrows

A second source of changes to MFGØ was the removal of two-way arrows from the activity diagrams. The decision to remove the 2-way arrows arose from a concern for the readibility of the diagrams. It was felt that the syntactic form, namely, a double-headed arrow with accompanying dots, did not clearly portray (in a graphic sense) the feedback loop it represented. The transformation of the two-way arrows into appropriate feedback loops did succeed in depicting the circular flow of data. On the other hand, the proliferation of new arrows added more pipelines to some already-crowded diagrams. It was also noted that, in the case of diagrams with numerous ICOM's, the deletion of a two-way arrow means that the feedback relationship between an input or control and an output would not be explicit because other entering and exiting ICOM's obscure the relationship. It was also noted that the removal of the two-way arrows invalidated a signficiant portion of the arrow trace information (which was based on a version of MFGØ having two-way arrows).

The removal of two-way arrows was also carried out for the IDEFØ model of Design (DESØ). The same problems as those of MFGØ -- increased clutter and loss of reciprocal relationship between initial and feedback arrows were noted.

3.5.3 Incorporate Changes to MFGØ

The upgrading of MFGØ to include the comments from industry review was completed during the option program.

3.5.4 Integration of QAØ

The QA (Quality Assurance) model was integrated into MFGØ using a revised procedure which is presented in Volume II of this report. This required the modification of about 20 existing diagrams and the addition of about 25 new diagrams. These new diagrams are, in most cases, redrawn child diagrams from the QA model. These additions required modification of ICOM's on existing MFGØ diagrams and the QA diagrams that were integrated as children of the existing MFGØ nodes.

3.5.5 Documentation of Subsystem Integration

Another source of MFGØ changes was the addition of subsystem support arrows. These appear as "mechanisms" that alert the reader to subsystem support roles. The subsystems incorporated into the architecture are SMC (Sheet Metal Center), MCMM (Manufacturing Control and Material Management) and QA (Quality Assurance). The mechanism arrows are labeled "subsystem" where more than one subsystem supports an activity. The resulting model is documented in Volume V of this report. The procedure involved is discussed in the following section.

3.5.6 Shortened IDEF Integration Procedure

A procedure for integrating IDEFØ models existed at the beginning of the Architecture Part III effort. The procedure was used for most of the IDEFØ integration discussed herein. However, it was found that the existing procedure required an effort at a level of detail which budget and available manpower will not permit:

- Too many nodes to examine (477 for MCDG)
- Too much time to execute detailed comparison (time for node estimated at 26 hours).

There were also objections based on the fact that the architecture was not updated.

The industry review also indicated that:

- Integration (IDEFØ) should be simplified
- Integration procedure (IDEFØ) needs modification to facilitate the ease or recognition of the relationship of subsystems to MFGØ.
- Validation and verification of subsystem models should occur during integration.

To meet this need, a revised procedure was developed.

Volume II of this report defines the procedure used to ensure that subsystems specified using IDEFØ can be integrated into the composite architecture of aerospace manufacturing as defined using IDEFØ (MFGØ). Such integration is a first step toward the ultimate integration of the physical subsystem into an actual plant operation.

A system whose evolution has been guided by this procedure will consist of functions which are clearly related to specified components of the architecture and whose interfaces to the rest of the architecture are precisely specified.

This document identifies several stages in the development of subsystems at which integration checks should be performed. For each stage, a different degree of rigor is required. This procedure defines in detail the stage in which the "AS IS" subsystem model is integrated to the "AS IS" architecture.

The procedure is a specific phase in an integration process which is intended as a ongoing aid to the developers and potential users of newly developed subsystems.

The complete process consists of three phases:

1. Scoping

2. Integration of the "AS IS" subsystem model

3. Integration of the "TO BE" subsystem model

Phase One, which precedes the phase discussed in this procedure, provides for a general scoping of the subsystem developers task. Before development of a new subsystem is initiated, the nodes in SystemØ to be replaced or supported by the subsystem are identified. This list of nodes provides the contracting office and the developer with a clear specification of the scope of development to be undertaken.

The list of nodes defines the areas to be further documented by the developer's "AS IS" model.

The definition of any node may be further refined by:

- further detailing of the node
- specification of arrows that are added, deleted, or changed in the context of the node.

Phase Two, which the procedure discusses occurs when the subsystem developer has completed an "AS IS" model. The subsystem developer specifies a comparison of functions and external interfaces between the subsystem model and the "AS IS" SystemØ. The comparison is not exhaustive, and discrepancies noted need not be corrected immediately. The list of discrepancies is used as a guide by the subsystem developer in developing his "TO BE" specifications and by the integration team for review at the next level of integration effort.

In the final phase, after this procedure is completed and when the subsystem developer has completed a "TO BE" IDEFØ specification of his subsystem, the comparison of functions and interfaces is repeated with greater rigor and is extended to an identification and consideration of functions which are related to, but not included in, the subsystem. Such functions are considered so as to obtain greater precision and rigor in the specification of SubsystemØ to SystemØ interfaces. Analysis of the interfaces may indicate a need to change areas of the architecture outside the subsystem to accommodate revised needs or outputs resulting from subsystem installation.

This final phase uses both "AS IS" and "TO BE" versions of SystemØ since new subsystems must meet two integration criteria. That is, the new subsystem must be useful in factories as they exist today and must

also fit smoothly into an image ("TO BE" model) of the updated and integrated factory of tomorrow.

It is within this total integration scenario that the procedure is designed to operate.

Figure 3-2 shows an overview of the total process just described. This illustrates the ultimate purpose and intended outputs of the process of which this procedure is a part.

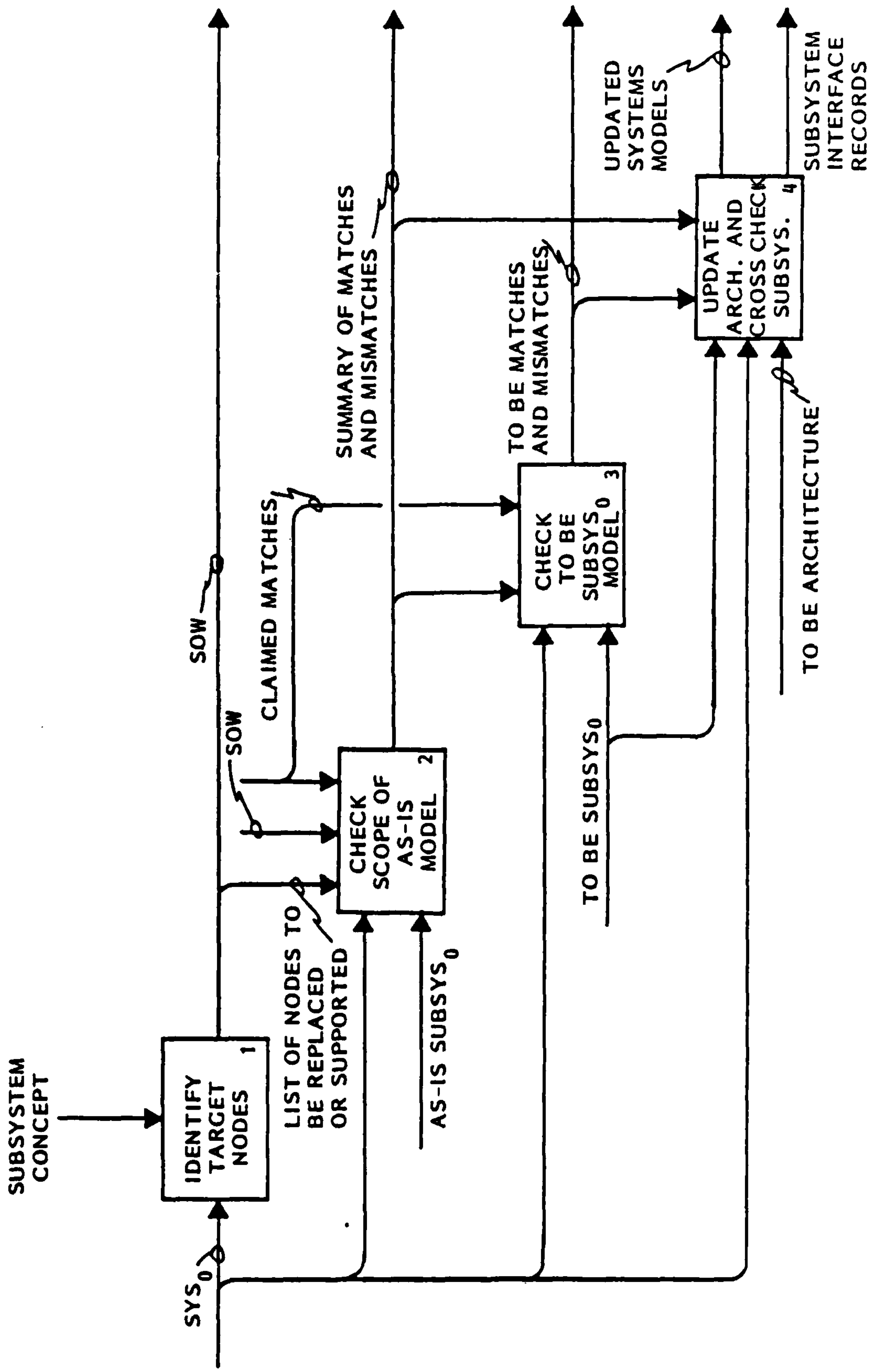
SUBSYSTEM CONCEPT
IDENTIFY TARGET NODES 1
SYS$_0$
LIST OF NODES TO BE REPLACED OR SUPPORTED
AS-IS SUBSYS$_0$
SOW
SOW
CHECK SCOPE OF AS-IS MODEL 2
CLAIMED MATCHES
TO BE SUBSYS$_0$
CHECK TO BE SUBSYS$_0$ MODEL 3
SUMMARY OF MATCHES AND MISMATCHES
TO BE MATCHES AND MISMATCHES
UPDATE ARCH. AND CROSS CHECK SUBSYS. 4
TO BE ARCHITECTURE
UPDATED SYSTEMS MODELS
SUBSYSTEM INTERFACE RECORDS

Figure 3-2

3.6 Information Model Maintenance

MFG1 is a composite information model of the entity and attribute classes associated with the "Manufacture (Aerospace) Product" function model. This composite view architecture is representative of the majority of aerospace manufacturers in the United States and is not intended to represent any specific company.

The model which is presented in Volume IV of this report extends and supercedes Volume IX - Composite Information Model of "Manufacture Product" (MFG1) published in June of 1981 as part of the ICAM Architecture Part II Project Priority 1102.

The process of developing an IDEF1 model involves subdividing the model into nodes and the modeling effort in phases.

A node represents everything that is known in any given phase about a particular aggregate of information called an entity class. Each node is assigned a (model unique) node number which is found in the lower left-hand corner of each model diagram. Each node individually passes through each phase of the model building effort. As such, the model does not move en masse from phase to phase, but rather moves as individual nodes, one at a time. It is common during model development to find nodes in each of the phases.

There are five phases in IDEF1 development. The first phase, Phase 0, establishes the context of the model to be produced and the purpose and viewpoint of the model.

Phase 1 involves the establishment of entity classes, their names, and their definitions. This is the true starting point of the model proper. Each node that starts here or is created later must be documented in Phase 1.

In Phase 2, entity classes are paired according to the observed associations between them. These associations are called relation classes, and are also given names and definitions.

In phase 3, two very important transformations take place. First, relation classes are refined. This usually involves the creation of new entity classes which are referred back to Phase 1 for incorporation. Second, since each entity class is thought of as representing many similar entities, a distinction is made by listing the unique properties of each entity class. These properties are called key attribute classes.

Finally, in Phase 4, the remaining attribute classes are identified, named, and defined. This also results in the creation of new entity classes which again are referred back to Phase 1.

The architecture presented in this report is based on the 1981 version, but differs from it in three ways.

The changes were intended to:

- Incorporate comments from industry reviewers.
- Utilize knowledge by development of IDEF1 models for subsystems
- Promote readability of the models.

The industry comments not incorporated during the firm program were now added to MFG1.

The compositing effort occurred in two stages. In the first stage the models developed in Project Priority 5501 Integrated Planning System and Project Priority 6201 Manufacturing Control and Material Management were composited into MFG1. This effort resulted in the addition of seventy-seven (77) entity classes (with associated relation classes, attribute classes, and key classes) to MFG1. In addition, the equivalence of many other entity classes within the three models was established.

In the next stage, QA1, the IDEF1 model of Quality Assurance, was composited with MFG1. This resulted in the addition of another eight (8) entity classes as well as the identification of more equivalent entity classes.

3.6.1 Document the IDEF1 Integration Procedure

Under this project, there was a need not only to composite the MFG1 model and subsystem models, but to develop a procedure for such compositing. The procedure calls for phases which closely parallel the phases used to develop an IDEF1 model initially. The complete procedure is presented in Volume II of this report. The remainder of this section provides a summary description of the integration procedure.

The IDEF1 integration procedure is designed to serve as a reference guide for the combining of two or more IDEF1 information models into a single information model. The concepts used to facilitate the combining of IDEF1 information models are described and depicted in the various examples contained in Volume II of this final report. This procedure is designed to be a working reference for the experienced information modeler.

This procedure assumes that the integration modeler has a working knowledge of IDEF1 information modeling methodology and has experience in building multiple IDEF1 information models.

The procedure is based on two assumptions regarding the quality of the models to be used in the integration process. These assumptions are: 1) the models correctly apply the IDEF1 methodologies, and 2) the models accurately reflect the factory views they represent. The quality of the source models will have an impact on the ease with which the models can be integrated. Models which do not correctly apply the IDEF1 methodology or do not accurately reflect the environments they represent can cause the resulting integrated model to lack credibility.

The modeler must also guard against any inadvertent changes to the views of the source models, as a result of the integration process. This can occur rather easily and the modeler should refer to the source models frequently during the integration process to ensure that the integrated model maintains the source model views.

The modeling team should consist of modelers and reviewers who represent the various source models. A team established in this way will provide additional guarantees that the source model views are maintained in the integrated model.

In the course of integrating IDEF1 information models, the modeler may find that, between the source models being integrated, there exist no common entity classes. As a result, "bridges" will have to be built between the models and new entity classes will result.

New entity classes may also be created from resolutions of discrepancies that arise as a result of the varying views of the models being integrated.

Any number of IDEF1 information models can be integrated using this procedure. However, the more models being integrated, the more involved the record keeping becomes to provide traceability back to the source models.

This procedure utilizes a five-phase approach to the development of an integrated model. This approach is consistent with the five-phase development of an IDEF1 information model. The documentation introduced by this procedure also parallels the IDEF1 information modeling methodology. The differences, due to the nature of the integration process, will become evident from the following discussion. The five phases for developing an integrated model are as follows:

<u>Phase Zero</u>

Phase Zero documents the context of the integrated model. In this phase, the scope of the integrated model is defined, its objectives are stated, and the source data identified.

Phase One

In Phase One, the objective is to identify and define the candidate entity classes to be used in the integrated modeling effort.

Phase Two

In Phase Two, the initial relation classes between the candidate entity classes will be identified.

Phase Three

In Phase Three, the key classes for each of the entity classes in the integrated model will be identified and defined.

Phase Four

In Phase Four, the integrated model will be populated with its non-key attribute classes.

The result of the integration process will be a new model which will reflect the combined views of all of the source models. It is of utmost importance that the integrated model accurately represent the views of the various source models and that the components of the source models are identifiable within the context of the completed integrated model. Maintaining this approach will ensure maximum usability of the model to the enterprise.

3.6.2 Integrate 5501 and 6201 IDEF1 Models with MFG1

The task of integrating the IDEF1 models from ICENT (6201) and IPS (5501) with MFG1 was carried out in two steps.

First, IPS1 and ICENT1 were integrated using the draft IDEF1 Integration Procedure previously developed. The model was developed to the equivalent completion of an IDEF1 Phase 2. The results of this integration were presented to the ICAM Community at the New Orleans Review Meeting.

Next the 5501 IPS/6201 ICENT Integrated Composite View (ICV) model was integrated with MFG1. The resulting MFG1 Composite View reflects the identification of attribute classes which fail the "no null" and "no repeat" test, but are not refined. This approach is consistent with the development of the 5501 and 6201 models. This integration has expanded the MFG1 model to include approximately one hundred entity classes and represents a signficant enhancement to MFG1's useability.

3.6.3 Incorporate Changes to MFG1

Recommended changes resulting from comments received during the October, 1981 coalition meeting were incorporated into MFG1. These changes were presented and accepted by the 1104 coalition industry reviewers at the January, 1982 New Orleans Industry Review. The category of changes which were made are listed below.

- New Entity Class(es) Required
- Relation Class Syntax Changes
- New Attribute Class(es) Required
- Key Class Changes
- Changes to Function Views
- Relation Class Label Changes
- Relation Class Definition Changes

3.6.4 IDEF1 Hierarchy Study

As a result of comments received from industry, it was determined to conduct a review of MFG1 focusing on improving the clarity and utility of the model. The primary objective was to determine whether the MFG1 entity classes could be grouped into an appropriate hierarchy.

After careful analysis, a decision was made to group entity classes based upon MFGØ partitioning. The entities were grouped according to their relationship to the manufacturing activities. Thus, entity classes are grouped and are associated with a given activity if the entities they represent are used implicitly or explicitly in an input, control, or mechanism of that activity, or if they are produced by that activity, or if they are used internally between two or more sub-activities. Groups containing large numbers of entity classes have been analyzed in greater detail and assigned to smaller groups, associated with third level activities. This effort lead to a significant increase in the number of FEO's associated with MFG1. The results appear in Volume VI of this report.

3.7 ICAM Glossary

By March of 1982, a preliminary glossary containing approximately 1000 terms had been established. The entries represented the pipelines of MFGØ and the entity classes and attribute classes of MFG1.

The coalition reviewed the preliminary MFGØ1 glossary in order to identify and prioritize those aspects needing refinement or expansion. An approach was established for accomplishing these objectives and the coalition began the task of writing glossary definitions for the functions contained in the MFGØ Architecture.

In addition, the glossary format established under the firm program was reviewed and tested. A final format was developed which is shown in Figures 3-3 and 3-4 along with definitions and explanations of the columns used.

The results of this effort are documented in Volume VII of this report.

SUBJECT					TRACE				SUBSYS USE	
NAME	USE	DEFINITION	CODE	SYNONYMS (LABEL)	ORIGIN(S) OR OWNER		TARGET(S) OR USER(S)		MODEL	N/D
					CODE	NAME	CODE	NAME		
1	2	3	4	5	6	7	8	9	10	11

GLOSSARY FORMAT EXPLANATION

1 NAME: The subject term in alphabetical order.

2 USE: The terms defined in this glossary are drawn from the ICAM MFG_0 and MFG_1 models. Terms taken from MFG_0 appear in that model as either a function name or as an arrow (pipeline) label. Those terms taken from MFG_1 serve as either an Entity Class name or as an Attribute Class name. Identification of the particular use of the term in question is coded in this column as follows:

F = Function Name
L = Arrow (Pipeline) Label
E = Entity Class Name
A = Attribute Class Name

3 DEFINITION: The definition of the subject term must be viewed within the context of the model from which it originated. The definitions are not meant to be Websterian; that is, they aren't rigorously applicable to general use. Rather, the definitions are relevant to the specialized context of the manufacturing model that uses the term.

4 CODE: This column carries the unique alphanumeric identifier that has been assigned to the subject term.
If the term is a Function Name, then the code is the Function Node Number.
If the term is an Arrow Label, then the code is the ICOM Code Number.
If the term is an Entity Class Name, then the code is the Entity Class Number.
If the term is an Attribute Class Name, then the code is the Attribute Class Number.

5 SYNONYMS: Any synonyms for the subject term that are listed in the MFG model appear in this column.

NODE:	TITLE:	NUMBER: 2

Figure 3-3

SUBJECT					TRACE				SUBSYS USE	
					ORIGIN(S) OR OWNER		TARGET(S) OR USER(S)			
NAME	USE	DEFINITION	CODE	SYNONYMS (LABEL)	CODE	NAME	CODE	NAME	MODEL	N/D
1	2	3	4	5	6	7	8	9	10	11

GLOSSARY FORMAT EXPLANATION (Continued)

6 ORG. CODE: Origin Code. If the subject term is an Arrow Label (signified by an "L" in Column 2), then column 6 identifies the origin in $MFG_{\emptyset}$ of that arrow.

7 OWNER NAME: If the subject term is an Attribute Class (signified by an "A" in column 2), then column 7 identifies the owner entity class in MFG_1.

If a subject term is a function node or an entity class, then columns 6 and 7 will be blank.

8 TRG. CODE: Target Code. If the subject term is an Arrow Label (signified by an "L" in column 2), then column 8 identifies the target of that arrow in $MFG_{\emptyset}$.

9 USER NAME: If the subject term is an Attribute Class (signified by an "A" in column 2), then column 9 identifies its inheriting entity class in MFG_1.

10 MODEL: Identifies the subsystem(s) of which the subject term is a part.

11 N/D: Column 11 carries a coded description of how the subject term is used in the subsystem named in column 10 . The character "N" means that the subject term and its definition both apply to the subsystem. The character "D" means that the subject term appears in the subsystem, but with a different definition.

NODE:	TITLE:	NUMBER: 3/4

Figure 3-4

3.8 Technology Transfer

In order to promote the dissemination of the products of the ICAM program, a series of presentation materials was prepared. Section 3.8.1 lists the materials, and Section 3.8.2 provides the material needed to obtain copies.

3.8.1 Abstracts of Approved Technology Transfer Documents Produced to Date

1. Technology Transfer Program Task Report (TM 110460000U)

   This report synopsizes the approach and development of the technology transfer material as well as recommendations for its future use.

2. Technology Transfer Execution Overview Presentation Manual (TM 1104600001U)

   This instructor's Presentation Manual contains copies of viewgraphs and is designed to help orient and educate executive level management relative to the need for a structured approach to implementing new manufacturing technology, thereby gaining productivity. It provides an overview of the U.S. Air Force's Manufacturing Technology Modernization Program's use of related IDEF applications, concepts, and procedures. It also covers the use of ICAM Architecture in planning and controlling these Manufacturing Technology Modernization Programs to upgrade the U.S. industrial base.

3. Transfer Executive Overview "Train the Trainer's (TM 1104600002U)

   This "Train the Trainer's" Manual, coupled with the above Presentation Manual, contains copies of viewgraphs and supplements for each viewgraph and is designed to give the instructor maximum efficiency in orienting executive level personnel. It employs a step-by-step process, section-by-section, dealing with "top-down" Manufacturing Technology Modernization planning and "bottom-up" project implementation concepts and procedures.

4. Technology Transfer Executive Overview Practitioner's Presentation Manual (TM 110460003U)

This Presentation Manual contains copies of viewgraphs and is provided to help teach an overview of the U.S. Air Force's Technology Modernization (TECH MOD) Program's use of related IDEF applications, concepts, procedures. It also covers the use of the resulting architecture and planning in controlling these Technology Modernization Programs to upgrade the U.S. industrial base.

5. Technology Transfer Practitioner's Train the Trainers Manual (TM 1104600004U)

This training manual contains copies of viewgraphs with narrative supplements for each viewgraph and is designed to give the instructor maximum efficiency in training manufacturing personnel. This manual provides step-by-step process, section-by-section, dealing with the concepts and procedures of IDEF Function Modeling, including reading, authoring, commenting on, and iterating IDEF Function Models.

3.8.2 Ordering Procedure

Use the Request Order Form presented in Figure 3-5 to request copies of Technology Transfer Documents, and submit to:

ICAM Program Library
AFWAL/MLTC
Wright-Patterson AFB, OH 45433

3.8.3 Develop Graphic Material

To support and encourage technology transfer, the program developed the following film reports.

1. Project Priority 1104 Management Summary Film Report (FLM110410010U)

This 7-minute film highlights objectives and benefits of the ICAM architecture. It summarizes the project achievements and presents an outline of the types of benefits that result from ICAM Architecture applications.

2. Project Priority 1104 Complete Motion Picture Film Report (FLM110410020U)

The movie opens with a fast visual history of airplane manufacturing. Comments on the value of the ICAM program to the aerospace industry form a thread which runs throughout the entire film. The film discusses the IDEF methodology, the achievements of the ICAM Architecture, Part III Program and depicts how integration is actually accomplished.

3.8.4 Ordering Procedure

Use the Request Order Form presented in Figure 3-6 to request copies of Project priority 1104 Film Reports and submit to:

ICAM Program Library
AFWAL/MLTC
Wright-Patterson AFB, OH 45433

APPROVED TECHNOLOGY TRANSFER DOCUMENT REQUEST ORDER FORM

Submit document requests to: ICAM Program Library
AFWAL/MLTC
Wright-Patterson, AFB, OH 45433

Document Configuration Management Number	Title of Document Requested and Document Date	Indicated (✓) Document Requested
TM 110460000U	Technology Transfer Program Task Report, May 1982	
TM 110460001U	Technology Transfer Executive Overview Presentation Manual May, 1982	
TM 110460002U	Technology Transfer Executive Overview "Train the Trainers" Manual" May, 1982	
TM 110460003U	Technology Transfer Executive Overview Practitioner's Presentation Manual, May, 1982	
TM 110460004U	Technology Transfer Executive Overview Practitioner's "Train the Trainers" Manual, May, 1982	

NAME ______________________________

TITLE ______________________________

COMPANY ______________________________

DEPARTMENT ______________________________

MAIL CODE ______________________________

STREET OR P.O. BOX ______________________________

STATE ____________________ ZIP ____________

PHONE # ________________

INTENDED USE:* ______________________________

______________________________ PROJECT: ____________

*No request may be processed without this information.

Figure 3-5

APPROVED FILM DOCUMENT REQUEST ORDER FORM		
Submit document requests to: ICAM Program Library AFWAL/MLTC Wright-Patterson, AFB, OH 45433		
Document Configuration Management Number	Title of Document Requested and Document Date	Indicated (✓) Document Requested
FLM110410010U	Management Summary Film Report (7 Min.)	
FLM11041002U	Complete Motion Picture Film Report (17 Min.)	

NAME ____________________

TITLE ____________________

COMPANY ____________________

DEPARTMENT ____________________

MAIL CODE ____________________

STREET OR P.O. BOX ____________________

STATE ____________________ ZIP __________

PHONE # ____________

INTENDED USE:* ____________________

____________________ PROJECT: __________

*No request may be processed without this information.

Figure 3-6

3.9 Validate Option Work

The coalition members attended and participated in the ICAM sixth annual Industry Days Conference at New Orleans from 17 through 22 January, 1982. A presentation was made regarding the objectives and accomplishments of the 1104 Program. The presentation emphasized the development and benefits of the ICAM architecture, as well as the effort being performed by the 1104 Program to maintain and improve its use. With this same theme, a booth was developed which indicated where and how the architecture was being used as well as a graphic description of the Project Priority 1104 activities to maintain it.

It was determined to be beneficial to present some of the material developed by the 1104 coalition to non-coalition members. These materials included the IDEF1 Integration Procedure and the integration of IPS (Project Priority 5501) and ICENT (Project Priority 6201) to MFG1. Both the integration procedure and MFG1 which was presented on 21 January 1982 appeared to be well received by those reviewers in attendance.

A final industry review meeting was held June 8 thru 10, 1982. Review of IDEFØ focused on the removal of two-way arrows and on arrow trace results. Review of IDEF1 focused on the development of more useful FEO's and on a detailed review of MFG1.

SECTION 4
RECOMMENDATIONS FOR FUTURE WORK

4.1 Introduction

The ICAM program has devoted significant time and resources to developing the Architectures of Design and Manufacture and the methodologies on which they are based. The result can become a significant contribution to the effort to modernize the country's industrial base. The use of the architectures and the methods is already widespread.

These recommendations are concerned with maximizing the future contribution of both the architectures and the methods. Some of the recommendations deal directly with the question, "How can these models and methods best serve the needs of the Armed Forces and of American industry?" Other recommendations deal with the possible improvements in the models or in the methodologies on which they are based.

It is hoped that other armed services, other industries, and individual companies will increasingly utilize the ICAM architectures directly, or as prototypes from which to develop architectures tailored to their specific circumstances. Such work will be easier and more productive if the lessons learned from ICAM's pioneering efforts are available to such users. This wider audience, and certainly the ICAM community, is the intended beneficiary of these thoughts.

With this audience in mind, the recommendations are divided into three sections. Section 4.2 discusses the uses of the models. Section 4.3 discusses ways in which the methodologies, and their transfer, might be improved. Section 4.4 offers comments on possible areas and directions for improvements in the models themselves. Such improvements might be carried out by either the ICAM program or by other users.

4.2 Use of the Architectures After Development

During the ICAM program, the architecture has been used primarily to scope subsystems and to relate subsystem models to an overview of the aerospace industry. These efforts would have been more fruitful if:

1. Integration had been initiated when subsystem efforts started, rather than after they were well under way;

2. Integration had focused on interfaces rather than on lists of functions;

3. A "TO BE" overview architecture had been developed;

4. Integration efforts were carried out top down rather than bottom up.

5. A meaningful role in scoping and integration had been developed for IDEF1 both as a support to the use of IDEFØ and as an independent factor in the integration process.

Each of these recommendations can and should be addressed in the future. Each of the recommendations is discussed more fully in one of the subsections which follow.

4.2.1 Recommendation 1 -- Pre-Integration

This recommendation is based on the thesis that it is easier to build pieces, subsystems, to conform to an overall plan than it is to build a plan which incorporates predeveloped pieces. The architectures provide the first step in developing a plan. The second step is to define the way in which the architecture is to be divided into subsystems with all of the subsystems in mind at the same time. These two steps provide an outline in which each subsystem has a role which is compatible with the roles planned for each of the other subsystems.

To add substance to the outline, still other steps should be taken before subsystem development begins. These steps can be local to a specific subsystem and the subsystems with which it will interface. They include:

a. Specification of how the new subsystem will differ from existing procedure;

b. Clear and firm definition of the interfaces between subsystems;

c. Clear and firm definition of each subsystem's authority and responsibility to access and update data.

Steps b and c are discussed more fully as part of the recommendations which follow.

An industrial user, of course, will seldom be able to follow this scheme from the beginning. Economics will dictate that some of the subdivision has already been defined by existing, expensive, packages which would not be easily divided. Such packages will often appear intact as part of the final overall plan. Their boundaries are among the boundaries which divide the architecture into subsystems. This does not argue, however, that the development of an overall plan is better left until later when even more fragmented pieces are likely to have been installed.

4.2.2 Recommendation 2 -- Specify Subsystem Interfaces

IDEFØ is founded on the belief that the "human mind can understand any amount of complexity as long as it is presented in easy-to-grasp, small chunks that are structured together to make the whole." Most errors in the application of IDEFØ flow from a failure to be sure that the pieces are properly "structured together to make the whole."

The cement used in the structuring consists of the interfaces between functions. If the subsystem developer knows what he will receive, and what he must supply, he can build a subsystem which can be integrated. That is, each subsystem will be designed to supply those needs of other subsystems for which it has been assigned responsibility. But interface definitions must go beyond IDEF models.

The interfaces as portrayed by IDEFØ and IDEF1 are conceptual. Integration is implemented only by interfaces completed in the physical world. This requires that, for each interface identified in IDEFØ, carriers, representation, and units must be specified.

For example, the integration team might document the need for a temperature to be passed from one subsystem to another. It would still be necessary for the supplying and the using system to operate on a set of standards such as Centigrade, ASCII, sent by serial transmission to some telephone at 1200 Baud. If the receiving system required instead an analog signal, say voltage equal to degrees Fahrenheit, then provision for a conversion interface would be required.

The same comments apply if the interface is completed by passing a transaction or by leaving the interface data in a database for later access by the using subsystem.

The specification of such interfaces will, of course, be unique to each enterprise although generic systems such as those developed by ICAM can provide a prototype on which each enterprise can build.

The efforts to develop such specifications will be even more important with the availability of networked systems such as IISS. It appears certain that the type of information just discussed must be supplied to the validation tables and common data model of the IISS before that system can provide a proper testbed for real world applications.

4.2.3 Recommendation 3 -- "TO BE" Overview

The integration task must have two faces like the Roman God Janus. One face must look to the "AS IS" state of an industry or an enterprise since a new system must surely fit into the existing environment. It would be futile to ask an enterprise to shut down for "just a few years" while a new, all encompassing system is built to suit its needs. Rather, there must be a plan which allows each new subsystem to be installed while

the enterprise continues to operate. The other face of this Janus-like task must look to the future since the end objective is to build a factory of the future.

The look to the future requires the definition of a "TO BE" architecture. Such architecture need not be carried to great detail. Rather, it should show the major pieces of which the future system will be composed. Special provisions are required to show the role of support systems such as Group Technology Classification and Coding (GTCC). GTCC, for example, has local impacts in such diverse areas as Design, Process Planning, and shop floor layout.

The "TO BE" model should, of course, be under configuration control since with use will come greater understanding and with greater understanding will come improvements. The "AS IS" model, equally, should evolve through successive revisions to capture planned, and unplanned, changes as they occur.

The resolution of the dichotomy between the present and the future views will require a second level of planning -- for temporary interfacing modules, for simultaneous installation of two or more modules, or for other conversion procedures. A series of "intermediate" models showing the planned phases through which the system will pass will help to smooth this part of the transition. Again, the reader should not visualize groups of models each the size of MFGØ. That would be monstrous and unacceptable. The models proposed can be quite small and still accomplish the intended purpose if (and only if) they are thoughtfully planned.

4.2.4 Recommendation 4 -- Top Down Integration

Any subsystem can be viewed as a cohesive entity, a single IDEFØ box. Much confusion about interfaces is eliminated if only the interfaces external to the box are examined by the integrator. Internal interfaces are the province of the subsystem builder.

The analysis of external interfaces can also be simplified if it proceeds from the top down. Initially, the integrator should be able to state the integration requirements in general terms relating to IDEFØ pipeline level arrows. Once these requirements are stated, more and more detailed views of each pipeline can be examined in the architecture. If the plan is consistent at the top level, the detailed examination, while necessary, is likely to hold few unpleasant surprises. Starting such an effort at the detailed level has been shown by the ICAM program to be beyond the resource level which can be justified.

4.2.5 Recommendation 5 -- Actively Use IDEF1

The first four recommendations have mentioned the role of information as interface without specific reference to IDEF1. This section addresses the role of IDEF1, and the extensive development work which appears to be needed to fully utilize its capabilities.

First, the IDEF1 models need to be annotated to show responsibility and authority to update and to access each piece of the model, preferably after extending the models to the attribute class level.

Next, or in parallel, a definition of integration should be developed which goes beyond the mere addition of data elements identified by the subsystem model to the main IDEF1 models.

A process for detailing the authorities and responsibilities mentioned above seems to be a minimal first step. In addition, a method should be sought to identify subsets of information which, like COBOL "working storage" elements, are internal to a specific application. It should be possible to suppress such subsets to allow more focused attention on the major issues of the models. The suppression should, of course, be voided when the subsystem itself is under review.

The integration procedure should include checkable guidelines for tying such subsets to the rest of the model, for recognizing overlaps in the subsets of two or more subsystems and, importantly, for being sure that all the data used by a subsystem is compatible with the main IDEF1 model even if the representation is not identical between the main model and the model of the subsystem.

At the same time, work should be undertaken to better define the use of IDEF1 in support of the IDEFØ type of integration. Related recommendations appear in the section on IDEF1 procedures.

4.2.6 Integration Summary

The use of the architectures for integration is under way. Our experience is now sufficient to point the way to further needed development. ICAM and other users should build on the lessons learned to date.

4.2.7 Other Uses of the Architectures

In ICAM, the use of the architectures has focused on subsystem integration. The integration applications should not be allowed to obscure the potential of the architectures for such uses as:

- employee training
- rationalizing the documentation of procedures

- involving more employees in system development
- database design

More frequent use of small models (ten to thirty diagrams for IDEFØ) of specific subjects would greatly facilitate such use.

4.3 Modification of Methodologies

The lifetime of ICAM, six years, has offered a major opportunity to test, evaluate, and reconsider the IDEF techniques. The six-year span covers a significant part of the life of IDEFØ and its predecessor technique. IDEF1 was formalized during the ICAM years. Both IDEFØ and IDEF1 have had significant use under ICAM. It is to be expected that experience with the methods under ICAM should have suggested possible areas for change.

An initial question which spans all IDEF methodologies is that of quality assurance. Is it not time to introduce for IDEF methodologies the same kind of control so routinely used for other aspects of industry? It is, of course, impossible to define objective measures for the application of syntaxes as simple as those of IDEFØ and IDEF1. The same statement can be made, however, about the use of the English language, a subject in which all of us have been graded.

A user of models would surely benefit if the results were subjected to independent validation and verification as is done with software. The review should be subject to challenge, but discussion of models based on quality concepts can only cause the level of quality in the models produced to rise.

The questions of quality and of technology transfer are closely related. The quality of some IDEF models now being produced, and the disappointment in many quarters with the IDEF methods seem to argue that the task of technology transfer has been underestimated.

In the software engineering discipline even experienced programmers expect to devote significant time to learning a new programming language. Perhaps learning an analysis technique requires more time than the few days now commonly allotted for IDEF. In particular, some form of on-going hand-holding (or perhaps hand slapping via the quality function) should be instituted.

4.3.1 IDEFØ Methodology Recommendations

The IDEFØ methodology encompasses: a syntax; the author/reader cycle; a set of concepts such as factory view, composite model, "AS IS" and "TO BE"; and techniques for integration. Each of these is considered separately.

The basic syntax has stood the test of time very well. Opinion still seems to be split on the use of two-way arrows but syntax is not a major cause of conflict. (The notes on quality assurance relate to laxness, not discord.)

The author/reader cycle was developed in an environment of limited, cohesive groups in a single physical location. The ICAM program has introduced the procedure to large, scattered groups of diverse character. The groups have, in some cases, simply bypassed the procedure primarily because of the time lag involved in circulating large model kits.

The first need is an absolute limit on the size of kits. Big kits breed delays which breed bigger kits which continue the spiral. A second need is a firm resolve to accept the implied resignations from the review team of evaluators who regularly ignore or delay kits. Also, ways to speed up the functioning of the central library should be explored. Allowing the kits to travel directly while the library posts after-the-fact records would help. Electronic transmission of kits is ideal. Smaller, project libraries might be considered.

These issues are not central to improving the application of IDEFØ, however. The primary recommendation for IDEFØ is the reconsideration of the definitions of composite models, "TO BE" models and of the ways the models relate. The original approaches were excellent first attempts. A method which more clearly focuses on the many existing similarities and which allows for clear identification of differences is needed. Certainly, companies with multiple plants, products, or even departments should recognize that there probably is a better way.

4.3.2 IDEF1 Methodology Recommendations

The IDEF1 methodology encompasses the same element types as IDEFØ plus a series of phases through which a developing model is to pass.

The IDEF1 syntax is essentially sound, but is open to a minor and a major criticism. A minor criticism, which is theoretical, is that questions are left unanswered: "What is the name for the graphic representation of a relation class," or "What rules govern the migration of alternate key classes?" The major criticism is that industry reviewers regularly complain that they cannot understand the models. Some of this problem relates to the training the reviewers have had, but that is not all. Model graphics are directed toward explicit guidance of database managers. The graphics must be slanted toward verification. That is, they must be meaningful to users. For internal use, SofTech is evolving a more flexible set of syntax rules which focus on users without losing the rigor of the existing syntax. We believe that some answers already exist. Others could be developed with reasonable effort.

The comments about IDEFØ kits apply equally to IDEF1. It is unfortunate that IDEF1 literature actually encourages large kits.

In the area of composite models and integration, there is serious work to be done. It is strange, for example, that parts (the entity class with Part Number as a key) in MFG1 are unrelated to and different from parts in DES1. One needs to examine relation classes and the implied migration of attribute classes to clearly understand the differences. The differences are not those between an engineering and a manufacturing bill of material. Our whole approach to IDEF1 should be geared to make such discrepancies almost impossible rather than very common as they actually are.

The circumstances, under which the display of entity classes or relation classes should be suppressed, need thoughtful consideration. Such suppression might be appropriate for: model validation, some types of model use, predefinition of scope for a subsystem, or compositing a subsystem model with an overview model.

Different definitions should apply to "integration" and "compositing" as is true with IDEFØ.

For either integration or compositing, judgment by the practitioner is required, but the definition for each process should provide greater traceability from one model to the other and should channel, document, and limit the use of judgment.

The concept of a preplanning phase and four development phases should be reexamined. Too many practitioners have never learned the basic meanings of "entity class," "relation class," "attribute class," and "key class." There is a tendency to learn the four development phases one must go through without learning how the items handled in each phase fit together into a unified syntax and semantics. The procedure seems, often, to replace the product in our technology transfer methods. Questions about basic syntactic errors are too easily avoided with answers like: "We haven't gotten to that yet, we're only at Phase three and a half" of the four development phases. Too many discussions proceed without a common understanding among those doing the discussing.

4.3.3 Technology Transfer

The basic syntactic elements or semantic elements of either IDEFØ or IDEF1 can be explained in about fifteen (15) minutes. A real grasp of either method, however, requires practice under supervision so that there can be feedback on the problems novices always encounter. This is the big element which must be added to technology transfer. This is the element which the IDEF1 phases tend to hide. The discussion has come full circle to the need for quality control.

4.4 Recommendations for Improvement of the Models

Most recommendations to be discussed for model development are grouped by model. The only multi-model recommendation is that MFG1 and DES1 should be reconciled as was mentioned earlier.

4.4.1 IDEFØ Model of Manufacture (MFGØ)

MFGØ is the oldest and most tested of the ICAM models. It provides a good basis for models of other industries. A few points are worth noting:

- The model should give more understanding of the details of a function rather than itemizing all of the types of subject items to which the function might apply;
- Some of the interfaces should be examined carefully to satisfy the user that the interface arrows fully support the function identified by the box title;
- Cross reference models from other viewpoints would be useful.

4.4.2 IDEFØ Model of Design (DESØ)

DESØ models the administration of the design process to a greater degree than it models the technical problems of that process. For example, it considers the level of design (preliminary vs. detail). It does not describe the technical decisions which must be made to progress from one level to the other. In fact, the end product being designed could be almost anything. The utility of this approach depends on the user's objectives.

If a user wishes to build computer aids for the task of administering design (assigning people, tracking progress etc.), the model provides a good basis for further work. If the user wishes to build computer aids for specific design tasks, or for configuration control, another viewpoint is needed. That is, a number of small models of different design tasks should be built.

The general recommendations which were given for MFGØ also apply to DESØ.

4.4.3 IDEF1 Model of Design (DES1)

DES1, like DESØ, is concerned primarily with the administrative side of design. That is, the information identified tends to be information about the status, or source of approval for each part of the design rather than information which constitutes the design itself.

Under these circumstances, it is especially important to differentiate positively between information and information about the carrier of the information. For example, maintainers of the model should note that "parts list item" (EC 118) and "next assembly use item" (EC119) both document the inclusion of part A in assembly B. That is, they are the same thing even though they appear on different documents.

Since, as noted earlier, DES1 should be reconciled with MFG1, most of the comments about that model apply equally to DES1.

4.4.4 IDEF1 Model of Manufacturing (MFG1)

The first priority for anyone maintaining or using MFG1 should be the populating of entity classes with attribute classes. This step would have the direct value of greatly increasing the data content of the model. It will have a greater value of improving the structure of the model which justifies postponing the adding of further entity classes until the attribute class additions are completed. The addition of attribute classes, if done with care, would alter the structure of the model.

The ultimate definition of any entity class lies in the attribute classes of which it is composed. Completing those definitions of the existing entity classes (by adding attribute classes) and then carefully examining the model will quickly eliminate many oversights which easily escape detection in the current state of the model.

Some examples are necessary to understand why this is true. A copy of the model would be helpful in reviewing the discussion.

One case where some attribute classes are available is Entity Class 414 "Drawing." One of the attribute classes listed is "Drawing Bill of Material." This attribute class is defined as "the structured alpha numeric matrix that identifies all the component details or dependent materials which comprise the part as defined by the engineering drawing." It happens that a matrix represents a forbidden repeating attribute, but that is not the issue. The attribute clearly concerns the part, not the drawing. In this case, it is easy to identify a confusion between the entity and the carrier of the information about the entity. As in DES1, information about a part (EC 6) has been confused with information about the drawing which only carries the information about the part.

In this instance, the mere presence of the attribute class is not enough to prevent error. But without the attribute classes, reviews of the model do not offer the basis for this kind of analysis.

It happens that Entity Class 414, "Drawing" is part of the illustration of another problem which the addition of more attribute classes would help to eliminate. The model shows that an Engineering

Release (EC 69) can "authorize use of" many Drawings (EC 414) and that each Drawing may be authorized for use by many Engineering Releases. If this type of m-n relation class was once shown explicitly (which it is not now), it needed resolution according to the syntactic rules of IDEF1. In fact, the model shows a "resolution" entity class "Released Engineering Drawing" (EC 12). Figure 4-1 shows these and a few other relevant entity classes.

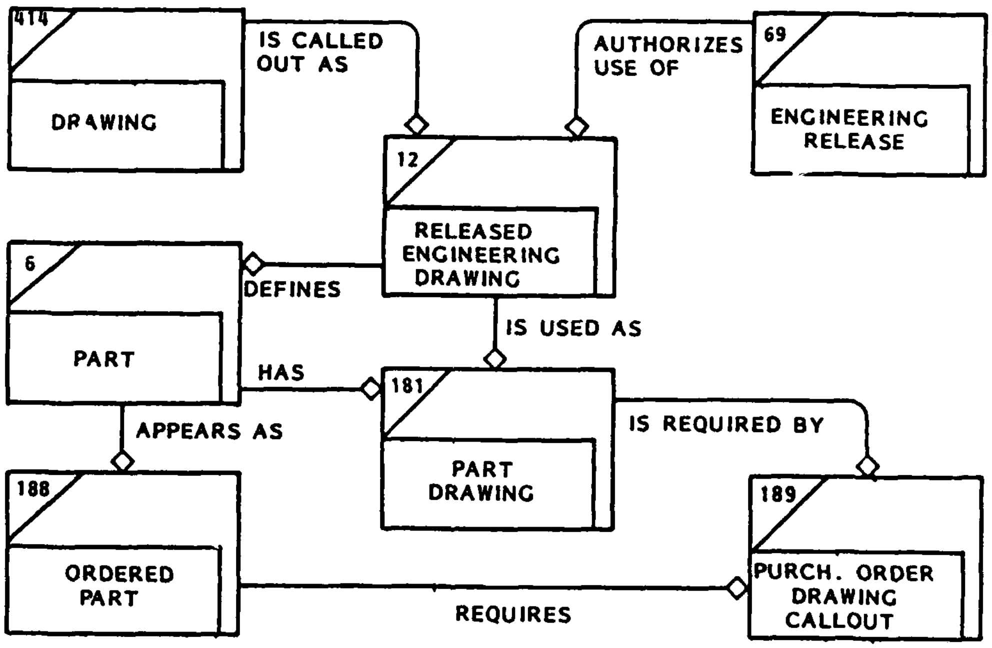

Figure 4-1

The resolution via entity class 12 is intuitively comfortable. Again, the addition of the relevant attribute classes would make the situation clearer. The reviewer must ask, "What are the attributes of the 'Drawing' and what other attributes relate to the 'Released Engineering Drawing'?" The syntax of IDEF1 requires that entity classes may share only the attribute classes which are key to one of them, in this case the drawing number.

On this basis, it is easy to conclude that the valid attribute classes of Released Engineering Drawing (EC 12) are the key classes of Drawing (EC 414) and Engineering Release (EC 69) and no others. Since the entity classes are generally unpopulated, the accuracy of the conclusion can only be a matter for speculation. In this case, it seems likely that a change of name for Entity Class 12 to "Release of Drawing" would more accurately guide our intuition -- it is the fact of the release, not the drawing which should resolve the m-n relation class. But, as suggested above, discussion at this length would be impossible and unnecessary if the attribute classes were available on which to settle the matter.

The change of entity class name just proposed illustrates a second recommendation for MFG1. For many entity classes, a name reflecting an event, a relationship or a reference would be more descriptive than a name reflecting a thing such as "Released Engineering Drawing." Examples of the proposed types of name include:

- Event - release of drawing
- Relationship - assignment (of employee to project)
- Reference - callout (of a tool by a process step).

Figure 4-2 shows the entity classes of Figure 4-1 renamed according to this recommendation.

Figure 4-2 is not a recommended form of the model. Hopefully, it illustrates that further changes in these structure of the model are needed.

The names of Entity classes 181 and 189 are strained. The existence of such entity classes must be questioned. Also, it seems more likely that a drawing, rather than only one of several releases of that drawing, "defines" a part. In addition, one might want to rename (or delete) several of the other attribute classes.

Actual resolution of the questions raised will require careful analysis based on the two recommendations offered:

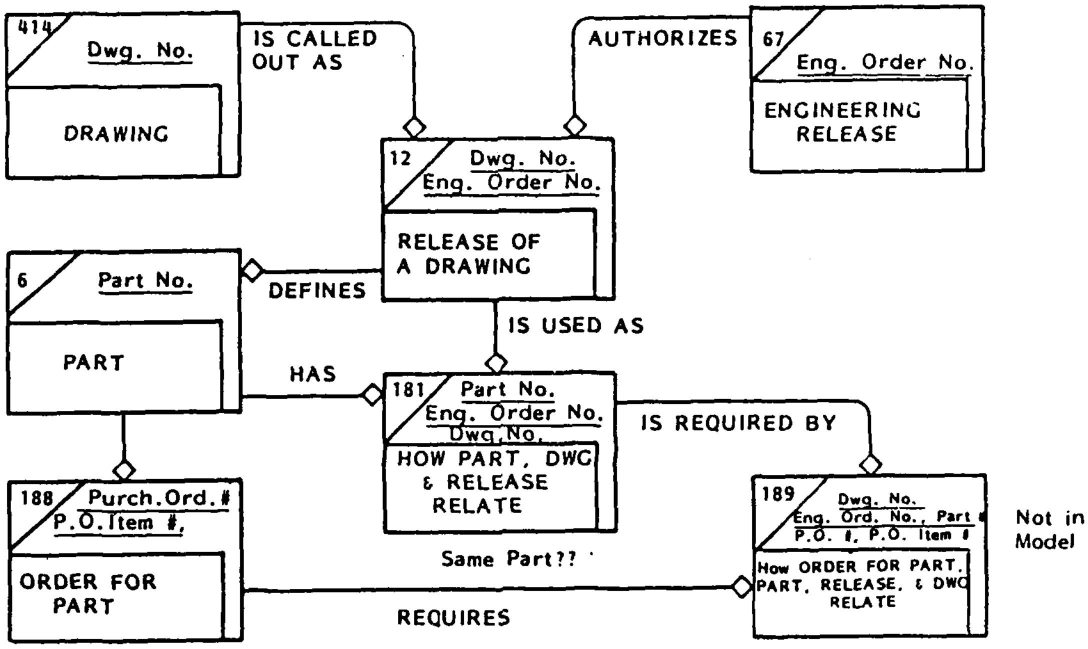

Figure 4-2

To repeat:

- All entity classes should be fully populated with attribute classes and the model should be reviewed on the basis of the attribute classes defined;

- Entity classes which appear to resolve m-n relation classes should be candidates for renaming, often on the basis that they refer to events, relationships, or references rather than to things.

SECTION 5
REFERENCE MATERIAL

5.1 Abstracts of Interim Technical Reports

The following Interim Technical Reports have been produced on this program.

5.1.1 List of Interim Reports

1. Interim Technical Report ITR110410001U, "ICAM Architecture, Part III," April, 1981 (Period 01 October 1981 - 30 March 1982)

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K	MFG1 PRIORITIZED RECOMMENDATION	K-1
L	DES1 - PHASE ZERO SCOPE AND CONTENTS - AUTHOR CONVENTIONS	L-1
M	DES1 - PHASE TWO ENTITY CLASS DIAGRAMS	M-1
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2. Interim Technical Report ITR110310002U, "ICAM Architecture, Part III, July, 1981 (Period 01 April 1981 - 30 June 1981)

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A	DES1 PHASE III DIAGRAMS	A-1

3. Interim Technical Report ITR110410003U, "ICAM Architecture, Part III," October, 1981 (Period 01 July 1981 - 3 0 September 1981)

4. Interim Technical Report IRT110410004U, "ICAM Architecture, Part III," January, 1982 (Period 01 October 1981 - 31 December 1981)

5. Interim Technical Report ITR110410005U, "ICAM Architecture, Part III," April, 1982 (Period 01 January 1982 - 31 March 1982)

6. Interim Technical Report ITR110410006U, "ICAM Architecture, Part III," July, 1982 (Period 01 April 1982 - 30 June 1982)

7. Interim Technical Report ITR110310007U, "ICAM Architecture, Part III," February, 1983 (Period 01 July 1982 - 31 October 1982)

5.1.2 Interim Technical Report, Document Request Order Form

INTERIM TECHNICAL REPORT DOCUMENT REQUEST ORDER FORM

Submit document requests to: ICAM Program Library
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ITR110410002U	"ICAM Architecture, Part III," July, 1981	
ITR110410003U	"ICAM Architecture, Part III," October, 1981	
ITR110410004U	"ICAM Architecture, Part III," January, 1982	
ITR110410005U	"ICAM Architecture, Part III, July, 1982	
ITR110410006U	"ICAM Architecture, Part III, July1982	
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